Fe, O, and C Charge States Associated With Quiescent Versus Active Current Sheets in the Solar Wind

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•An International Space Science Institute (ISSI) Study Team* was formed to study **current sheets** at the Sun and in the solar wind

•As part of that study, we have examined charge states around current sheets near magnetic clouds in the solar wind, using SWOOPS, SWICS, and MAG data from Ulysses and SWEPAM, SWICS, and MAG data from ACE.

•In order to distinguish charge state signatures related to solar activity, 'quiescent' current sheets, associated with CIRs, are used for comparison.

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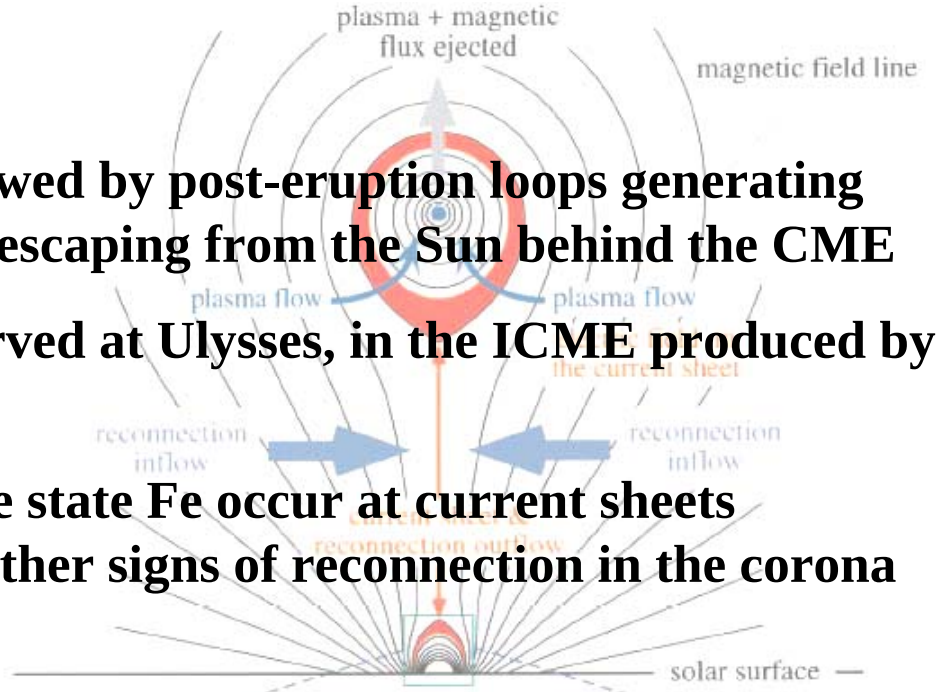
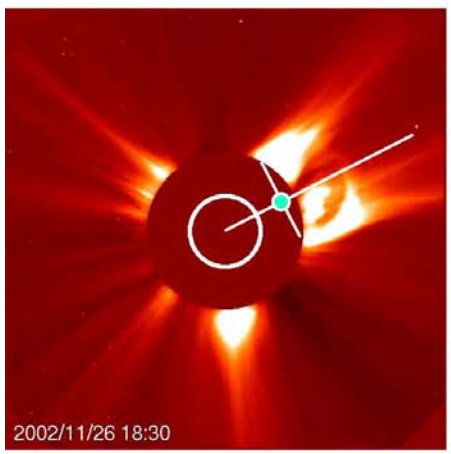
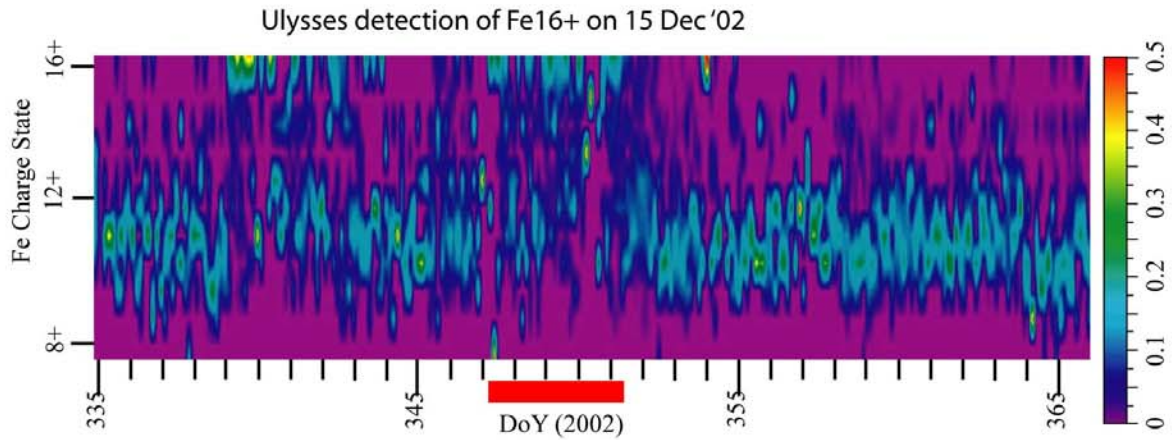
The motivation:



- **A CME was observed to be followed by post-eruption loops generating >8x10^{6}K Fe at 1.7 Rsun that was escaping from the Sun behind the CME**
- **2-3 weeks later, Fe16+ was observed at Ulysses, in the ICME produced by the eruption.**
- **How commonly does high charge state Fe occur at current sheets associated with ICMEs and can other signs of reconnection in the corona be identified?**

UVCS observation of Fe17+ being produced at 1.7 Rsun on 26 Nov'02, along the radius towards Ulysses.





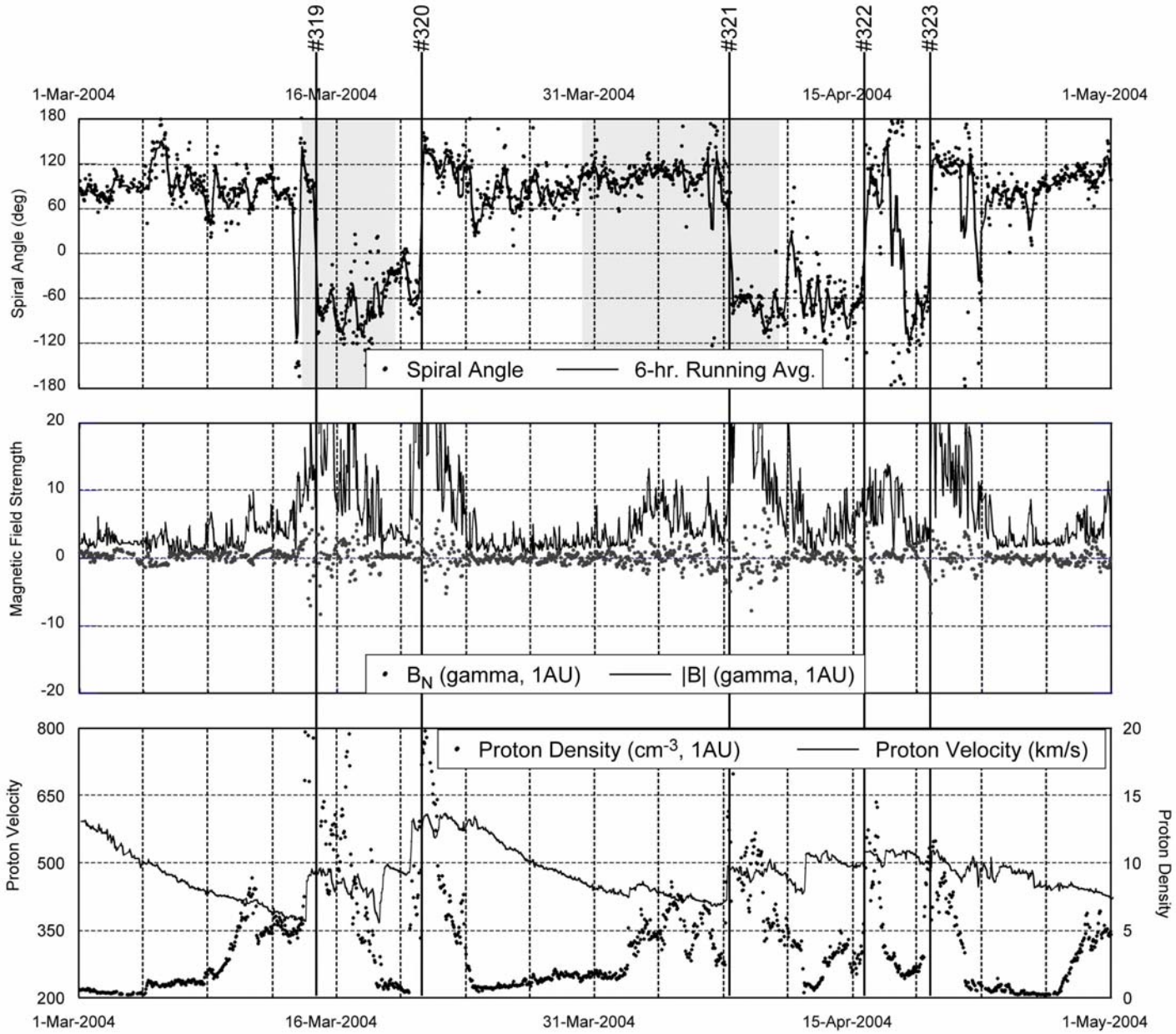
Bemporad et al., *Astrophys. J.*, **638**, 1110-1128, 20 Feb. 2006.

To proceed with Ulysses (& ACE):

1. Select a large number of CS crossings
2. Describe the solar wind characteristics at and near each crossing
3. Sort the crossings according to the (many) different characteristics
4. Superpose the results for various classes of crossing
5. Do the same (a totally new thing) for solar wind composition and ionization state (Ulysses/SWICS instrument)

We selected ~400 relatively isolated and sharp current sheet crossings from the full Ulysses data set, and a comparable number from ACE.

At right: Two months of data in 2004 when Ulysses was near the equator and 5 AU, just before sunspot minimum. There are two HCS crossings per rotation plus an apparent ICME in mid-April.



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An example of HCS crossing identification and classification.

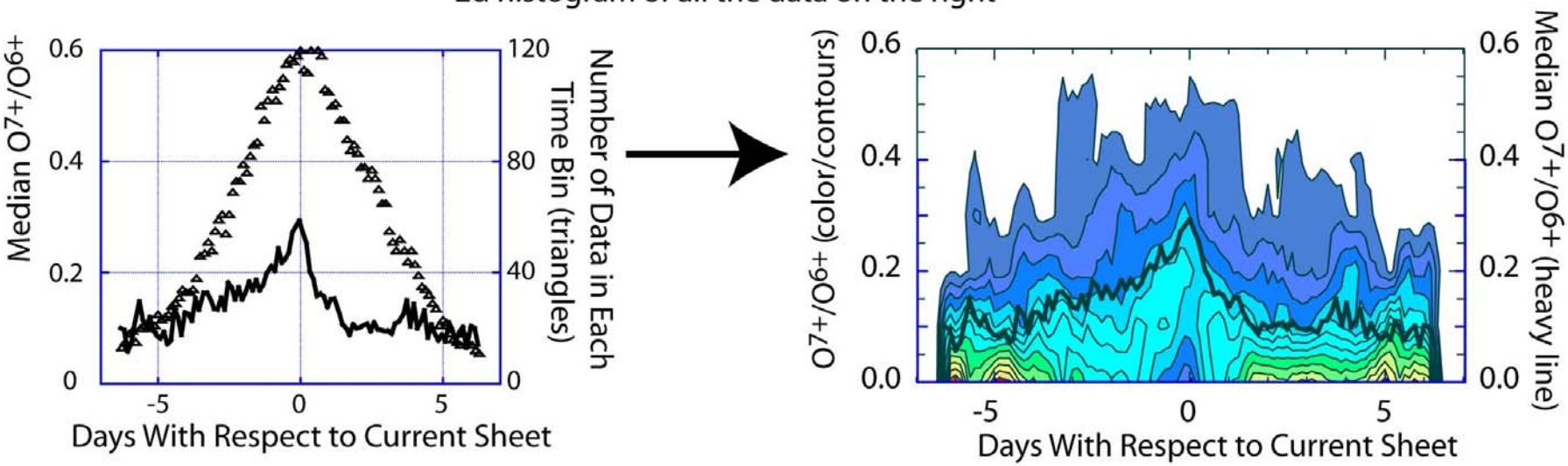
Note the interval selected around the CS time. It is defined by no major changes in magnetic field character - especially no other current sheets.

```
320       Interval number
2004    Year
21mar_0430/16mar_0530/30mar_0230    date/time   Center/Start/Finish
116215    Center hour
116096    Starting hour
116429    Ending hour
333       Length (hours)
-1.37    Latitude at center time (deg, - South, + North)
5.37       Radius at center time (AU)
1       Clean, isolated crossing
0       Multiple, isolated crossing
1       At the front of a CIR/CME, perhaps embedded in the shock ensemble
0       At the back of a CIR/CME, or in a CRR
0       At the front of a possible magnetic cloud
0       At the back of a possible magnetic cloud
0       Apparently following an ICME
0       In a magnetic cloud (a rotation vs. a sharp reversal)
3       Quality (0=reject, 1=poor, 3=okay, 5=perfect)
0       Reserved
0       Reserved
0       Reserved
```

Superposed epoch plots of epochs lying at current sheets in Ulysses data:

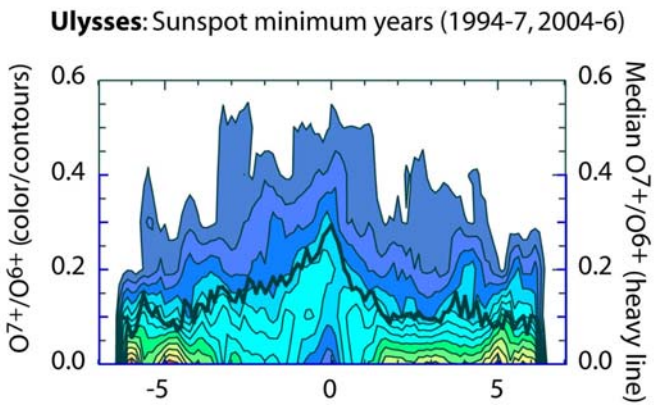
Ulysses: Sunspot minimum years (1994-7, 2004-6)

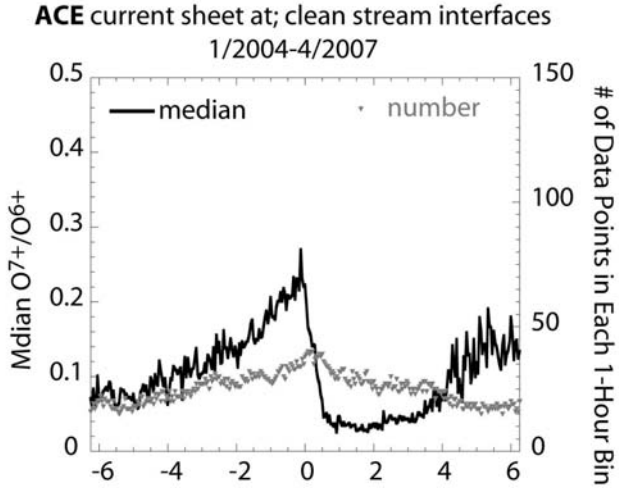
Plot from left superposed on contours in a
2d histogram of all the data on the right



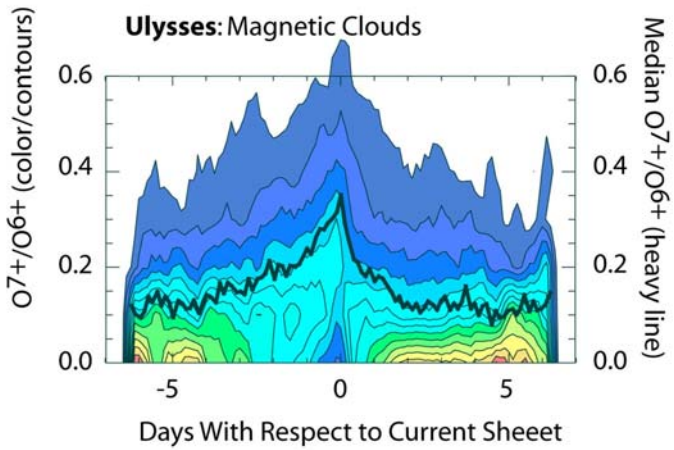
O^{7+}/O^{6+}:

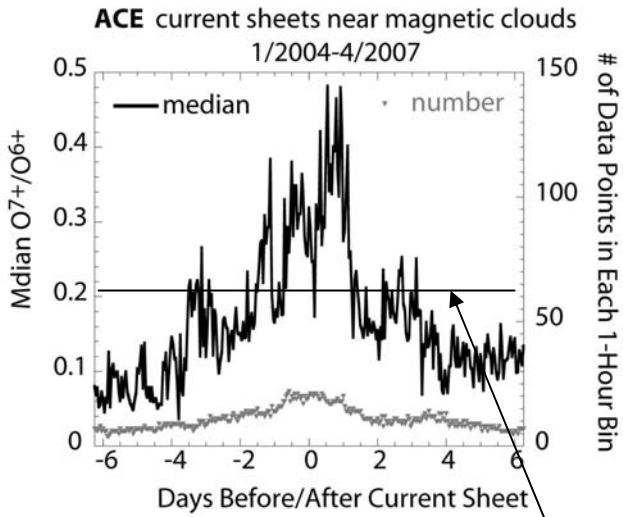
Quiescent





Active





Avg. for Vp<450 km/s.

- O^{7+}/O^{6+} is enhance at current sheets (where V is low).
- It is ***more enhanced*** at active than at quiescent current sheets.
- The enhancement seems to decrease with distance.

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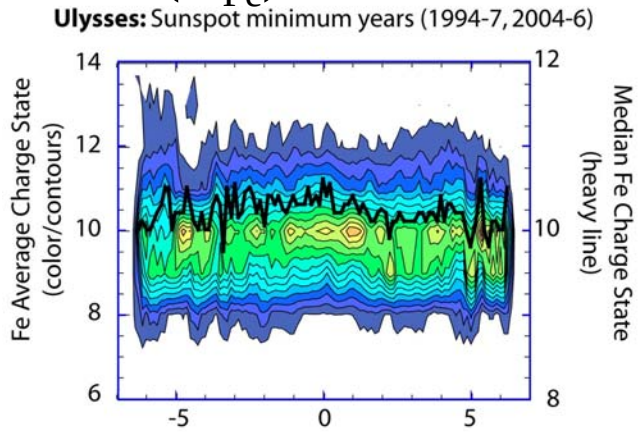
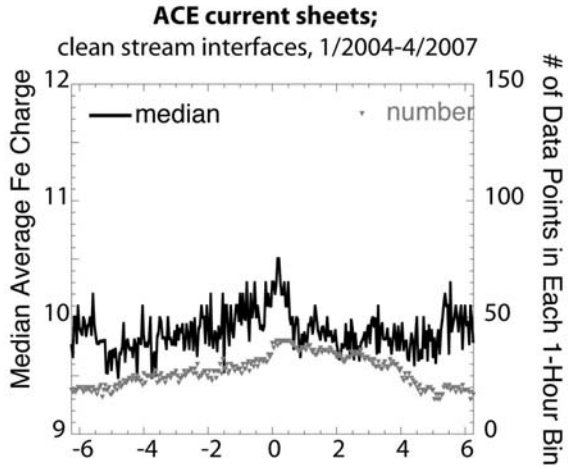
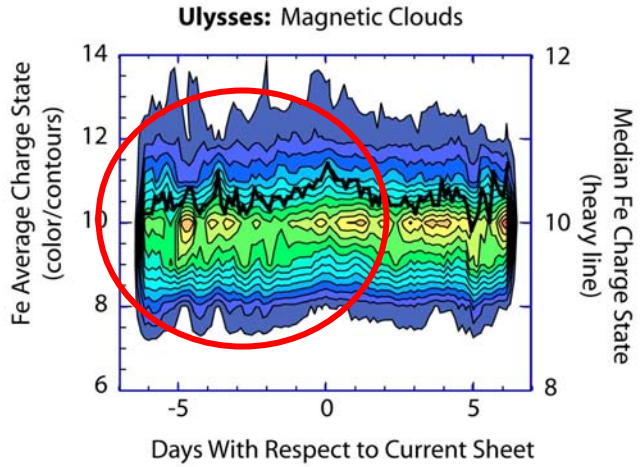
Fe Average Charge State (Q_{Fe}):

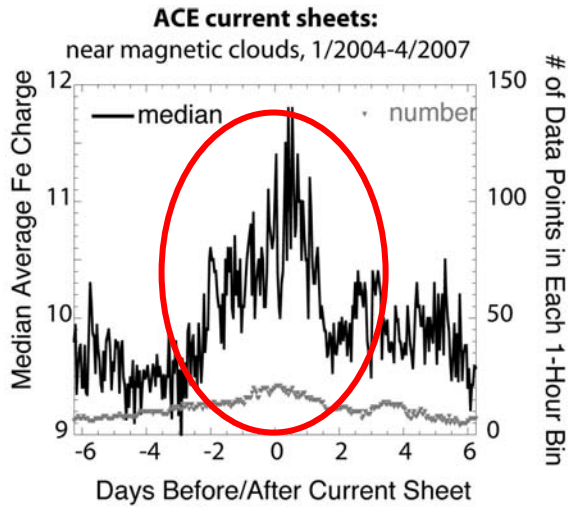
Quiescent





Active





- Q_{Fe} is little, if at all enhanced at quiescent current sheets.
- Q_{Fe} is ***enhanced*** at active current sheets, ***but there is no island around zero-lag***.
- The enhancement seems to decrease with distance.

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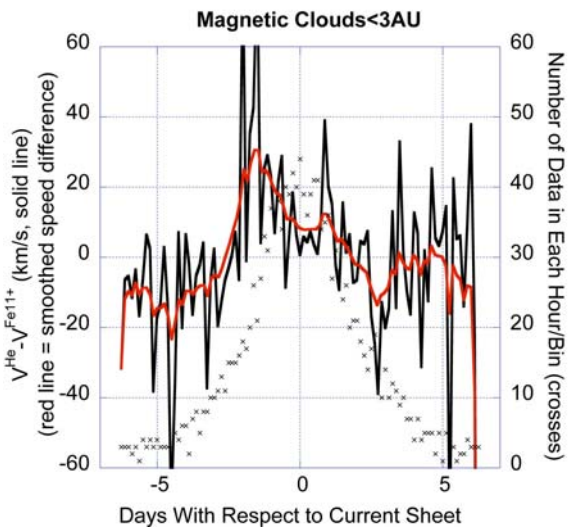
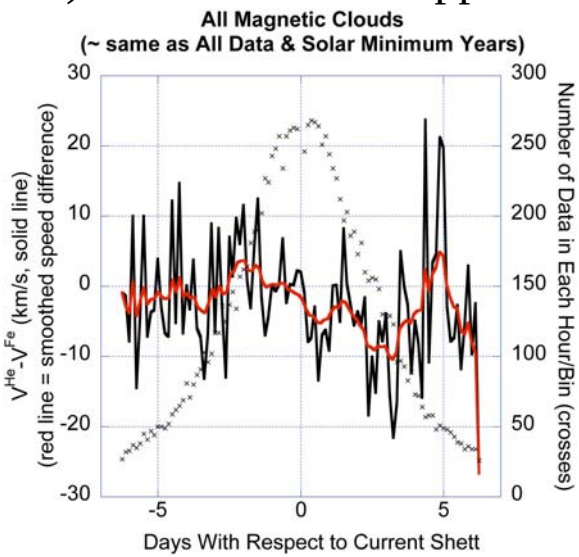
Decrease in enhancements with distance? - a $V_{Fe,O}$:V_{He} velocity differential?:

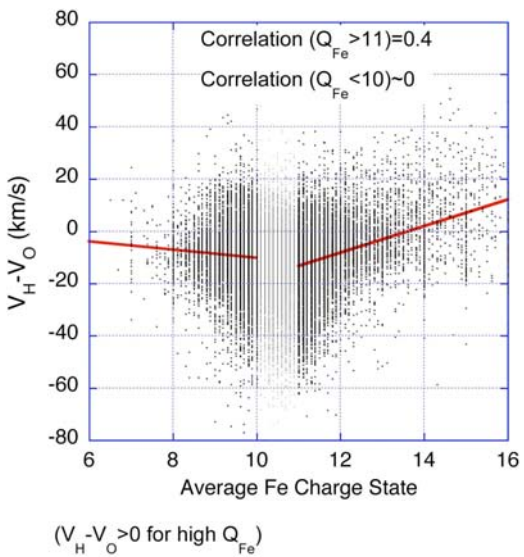
There is a differential speed between Fe and He (Fe lags He) that seems to disappear with increasing distance.

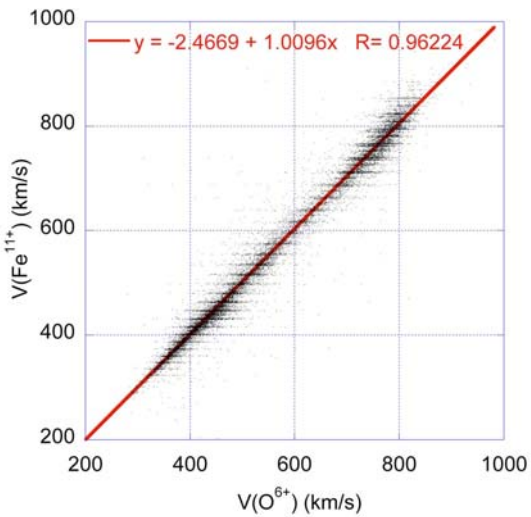




The Fe-He differential flow seems to depend on Q_{Fe}.

Plots using the full Ulysses data set





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Summary & Conclusions

- Q_{Fe} and O^{7+}/O^{6+} (and C^{6+}/C^{5+}, for which the O charge state is a proxy) are enhanced at the heliospheric current sheet.
- Q_{Fe} and O^{7+}/O^{6+} are more enhanced at at current sheets associated with magnetic clouds ('active' current sheets).
- Q_{Fe} and O^{7+}/O^{6+} enhancements seem to fall with increasing heliocentric distance (!)

Discussion:

- Enhancement of charge state near active current sheets is probably associated with coronal reconnection more so than with photospheric activity*
- There is no sign of 'jetting' of Fe that might be directly associated with the coronal reconnection. Due to collisions, to see this even at ACE would have been surprising.
- There is a small differential flow between Fe(O) and He (Fe lags) at current sheets that disappears with increasing distance and with decreasing charge state. It may be a consequence of differential Coulomb drag in streamers.
- The lack of a large high-Q_{Fe} or even an 'island' at zero-lag in the superposed epoch plots implies that the high-Q_{Fe} enhancements seen in ICMEs probably represent a range of conditions ranging from relatively cool ejections with little charge-state enhancement up to the hot ejections reported by Bemporad et al. (2006).

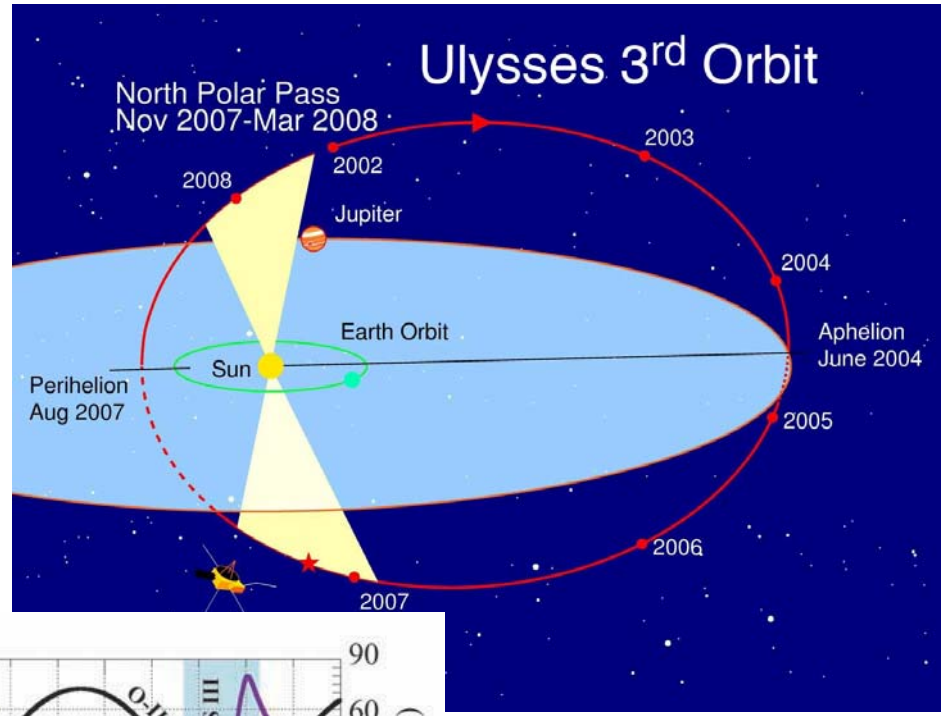
*(Rakowski et al., 'Ion Charge States in Halo Coronal Mass Ejections: What Can We Learn About the Explosions?', *Astrophys. J.*, **667**, 602-609, 20 Sept. 2007)

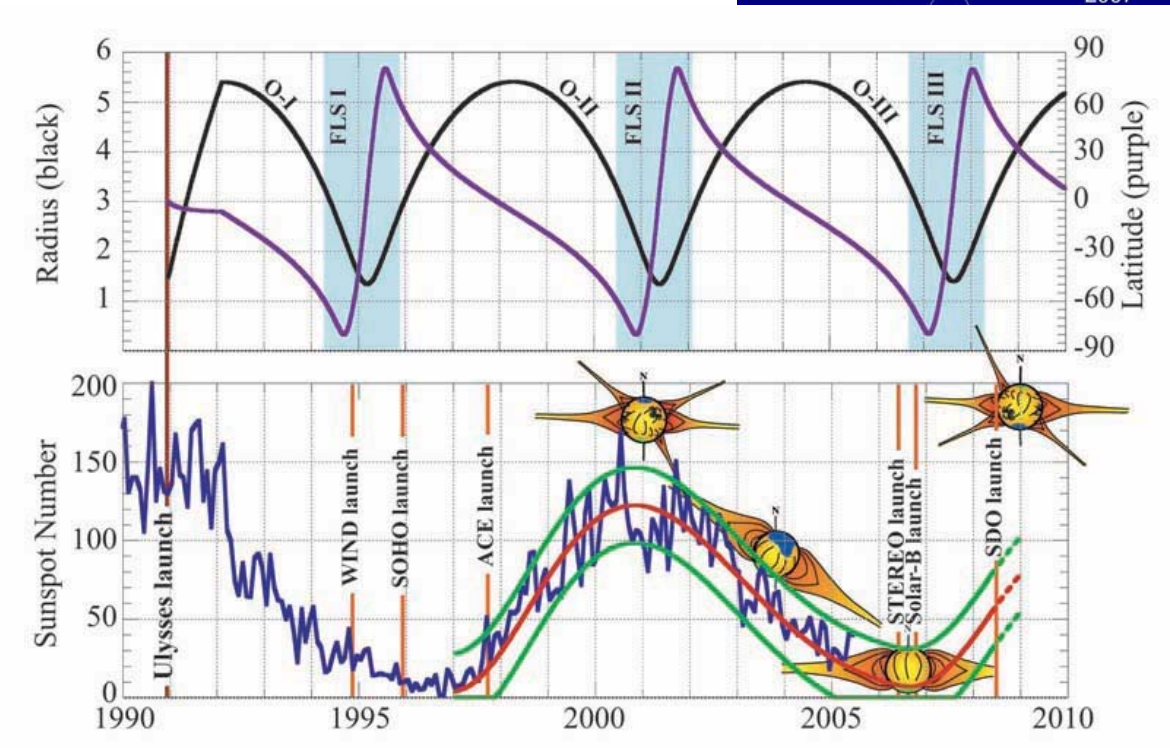
Ulysses:

*1.34 AU to 5.4 AU

*sweeps from 80^{o}N to 80^{o}S

*6 year orbit





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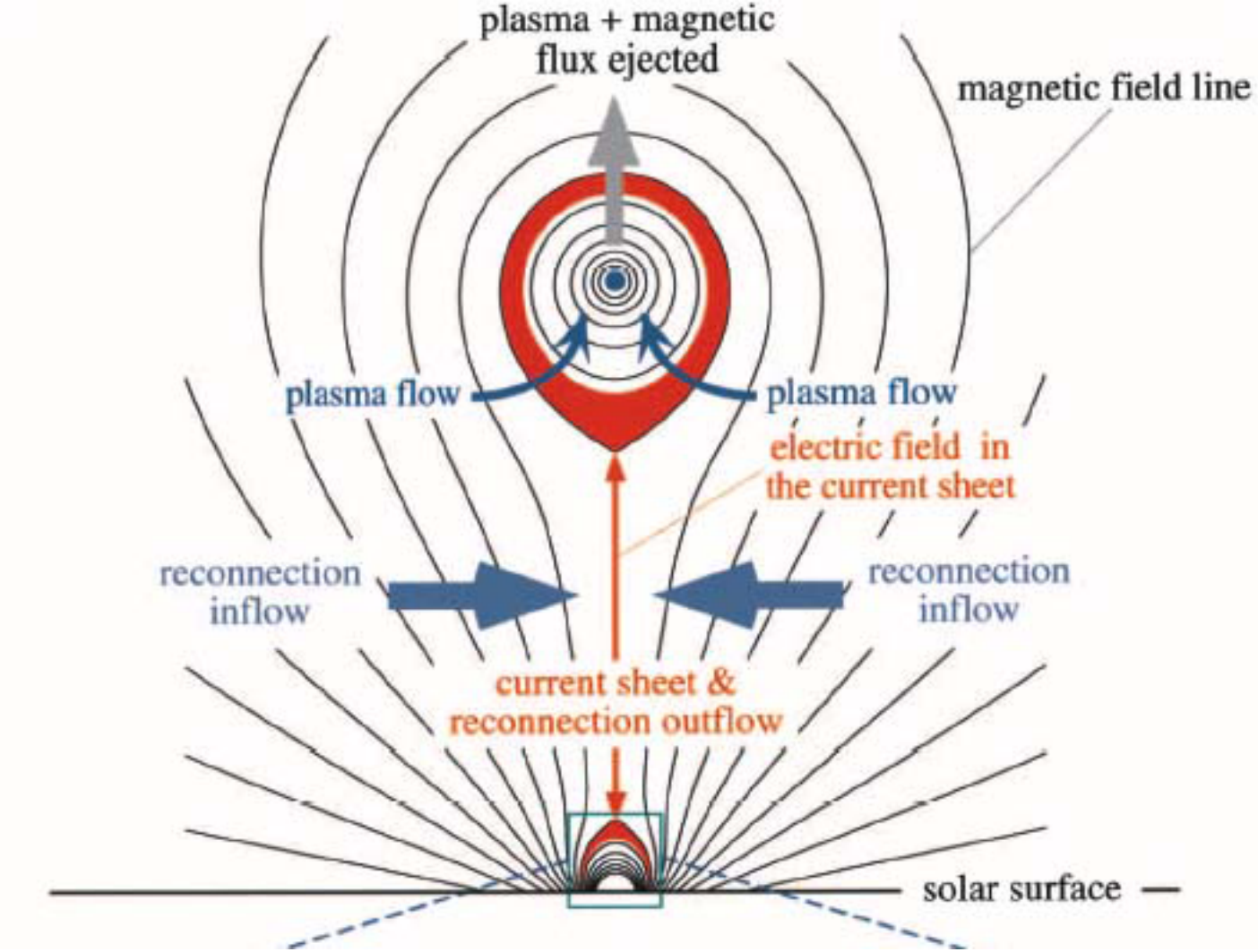

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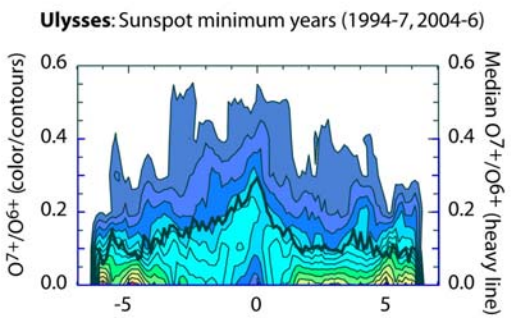

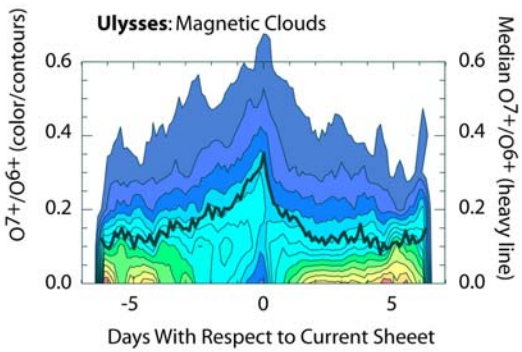

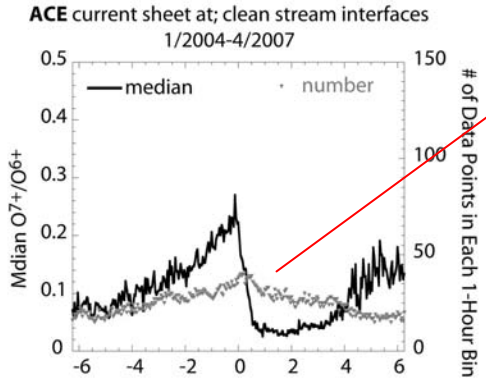

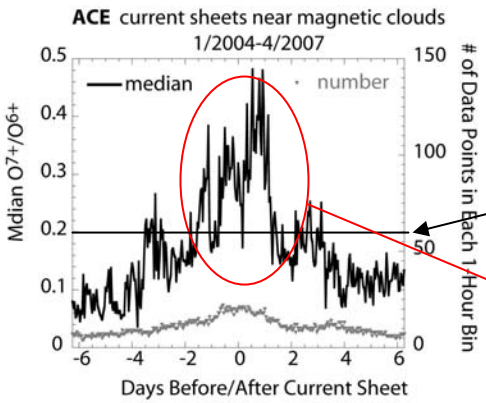

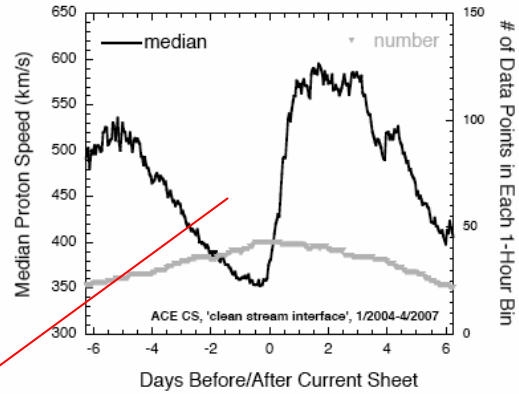

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